

InGaN Photocathode Development

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Outline

- Research Plan
- Nitride Semiconductor Material Properties
- MBE Growth
- Materials Characterization
- Surface Activation and Quantum Efficiency
- External Bias and Intrinsic Gain
- Tube Sealing

Research Objectives

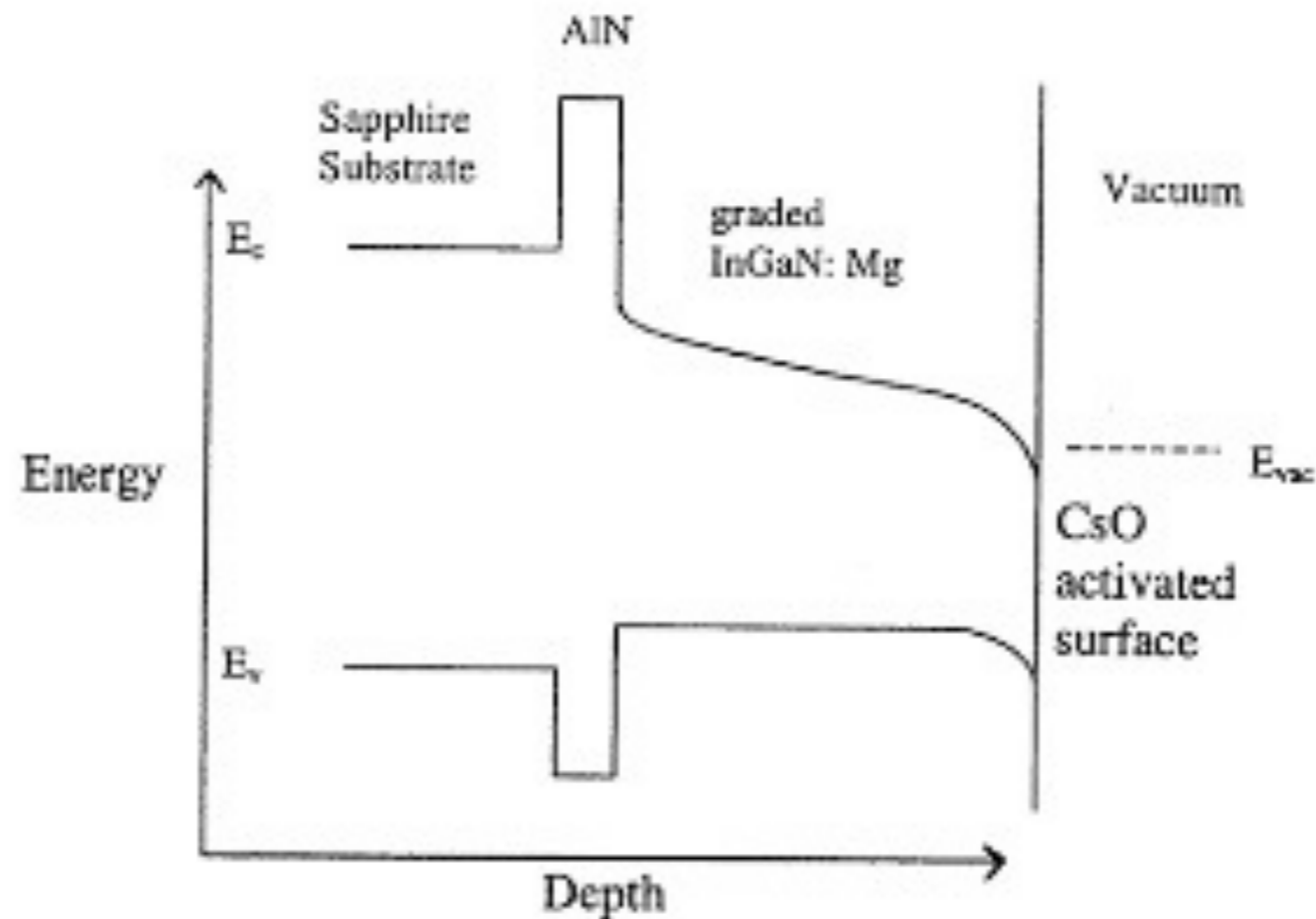
- Explore cathodes with longer wavelength sensitivity by incorporating more Indium.
- Explore techniques for surface restoration after transfer (cleaning, bias voltages)
- Explore growth on amorphous substrates/MCPs
- Complete tube-sealing system for Indium bonding to devices for transfer/characterization.

Semiconducting Nitrides

- Crystal structure - hexagonal or cubic
- Band gap energy - ranges from 0.8 to 6.2 eV
- Epitaxial growth on sapphire window substrates (other substrates such as AlN, GaAs and Si are possible)
- n-type carrier conductivity - intrinsic and doping with Si
- p-type carrier conductivity - doping with Mg
- Negative electron affinity surface with Cs activation (intrinsic NEA possible with AlN)
- Amorphous GaN predicted to have a ``clean gap''

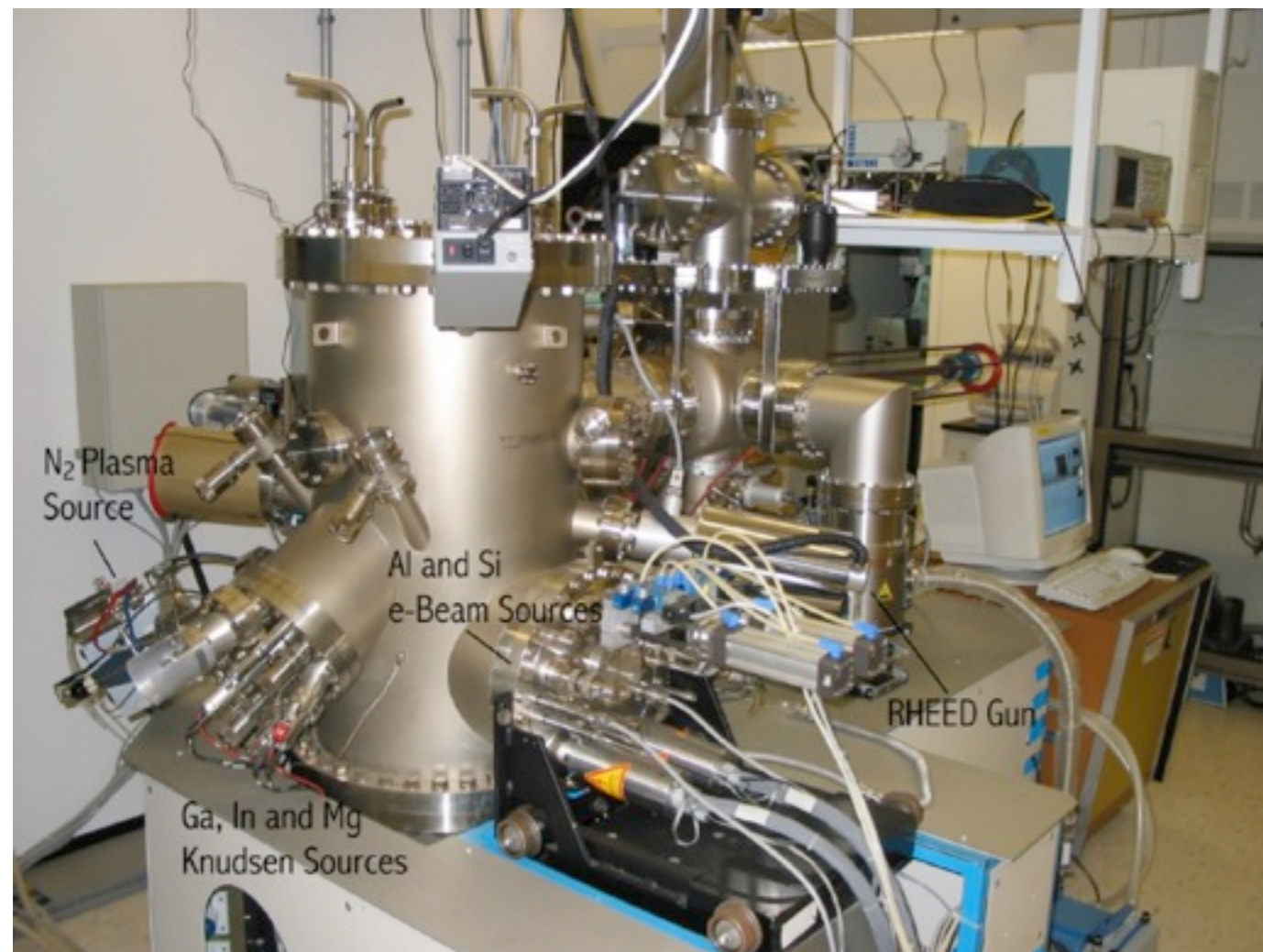
Energy Band Profile

- Our approach is to use MBE for heteroepitaxial growth of nitride semiconductors with a band structure tailored to promote efficient transport of photoelectrons to the photoemissive surface.



MBE Growth of Photocathode Layers

MBE utilizes a UHV growth chamber with a rotating, heated substrate and shuttered beams from the different sources. Our Nitride system also includes a nitrogen plasma source.

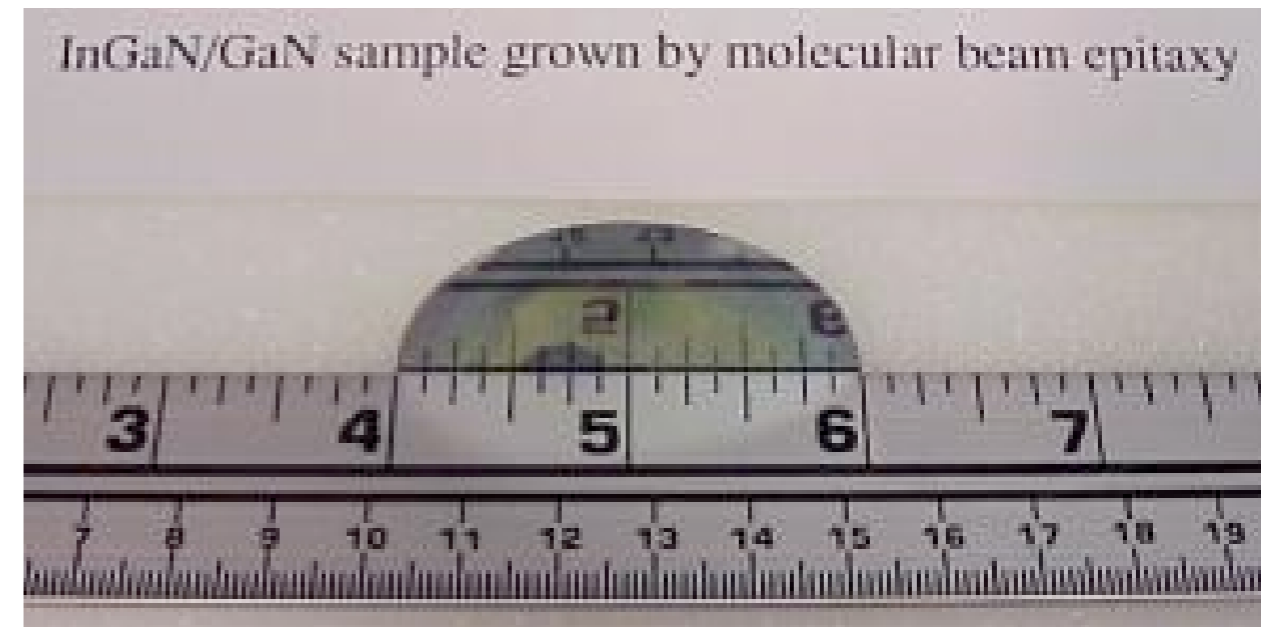
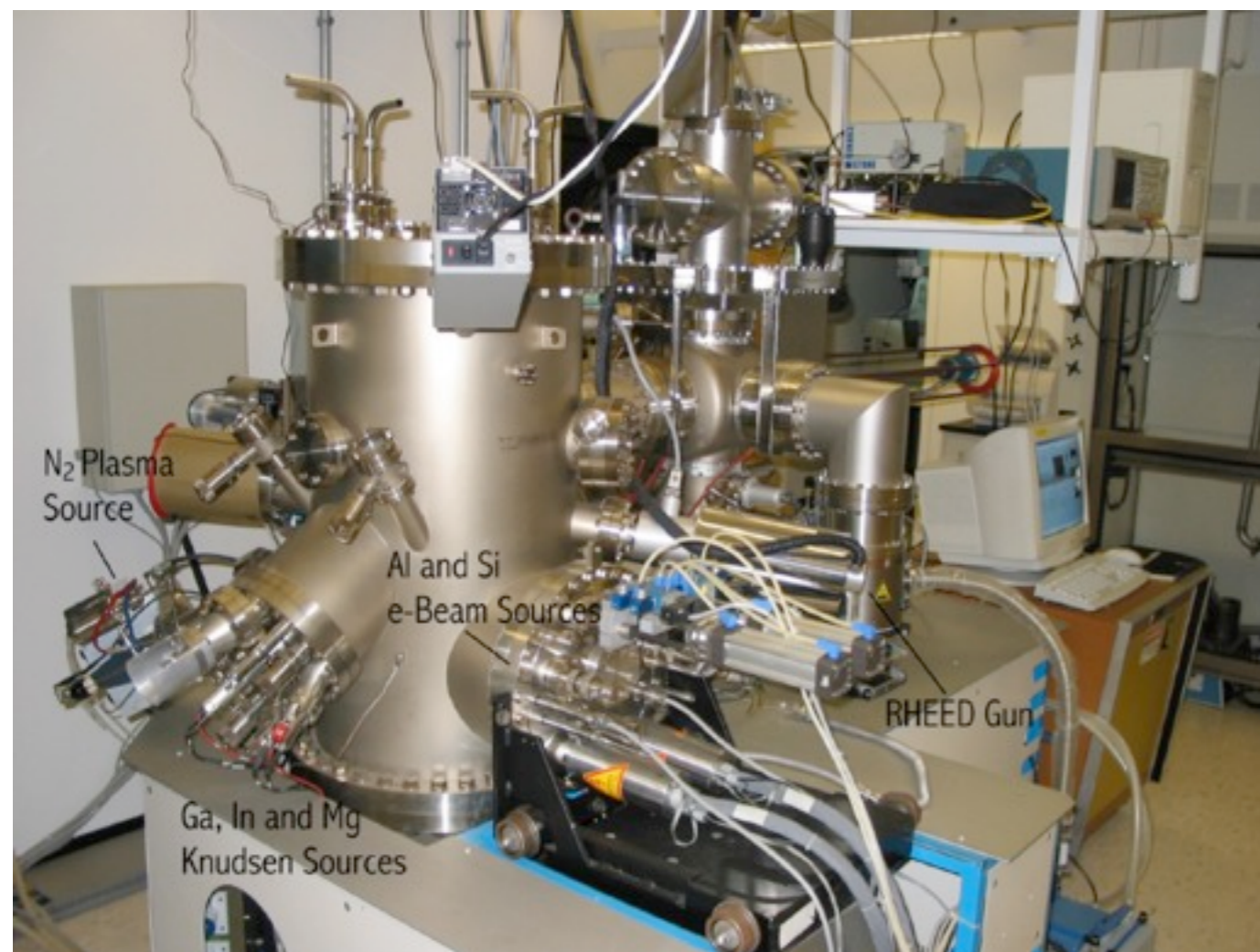


Our system currently has the capability of growing wafers up to 3 inch in diameter.

A production system could yield multiple 4" wafers per day.

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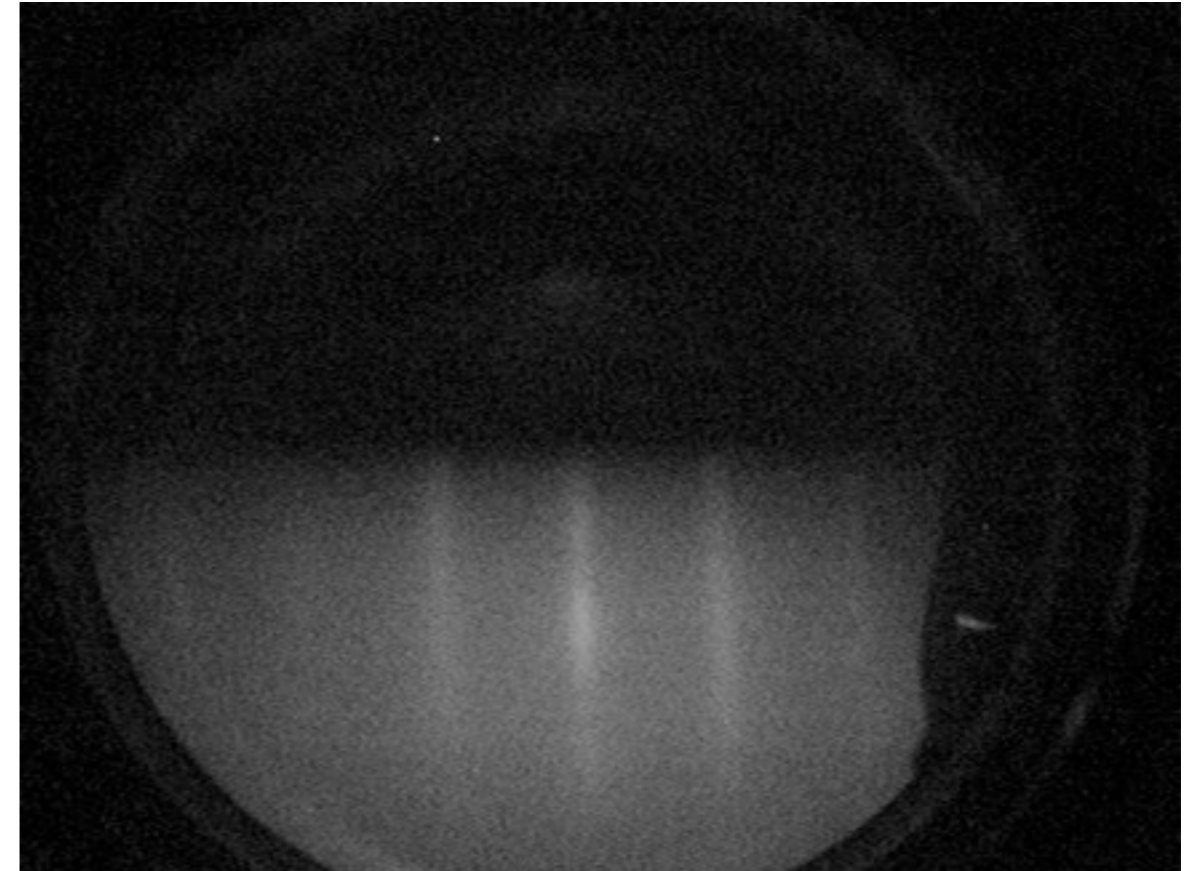
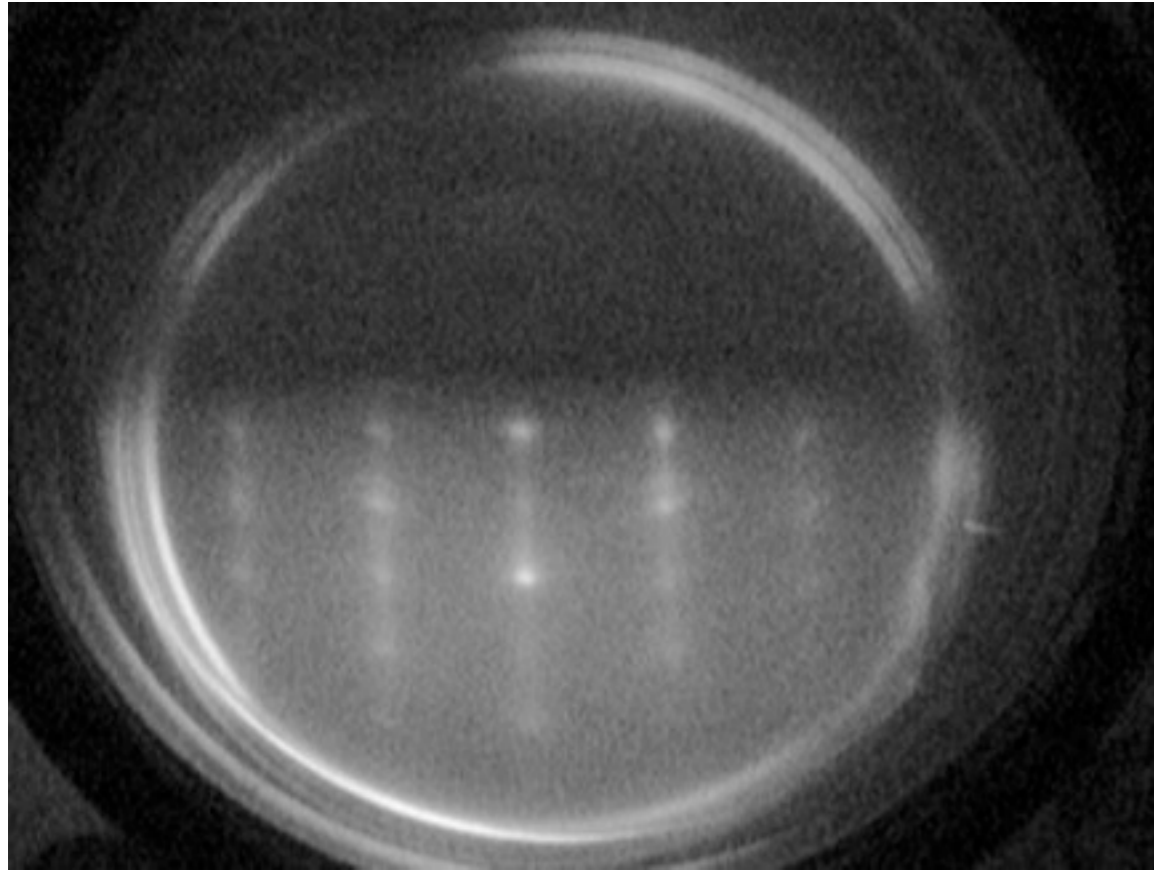
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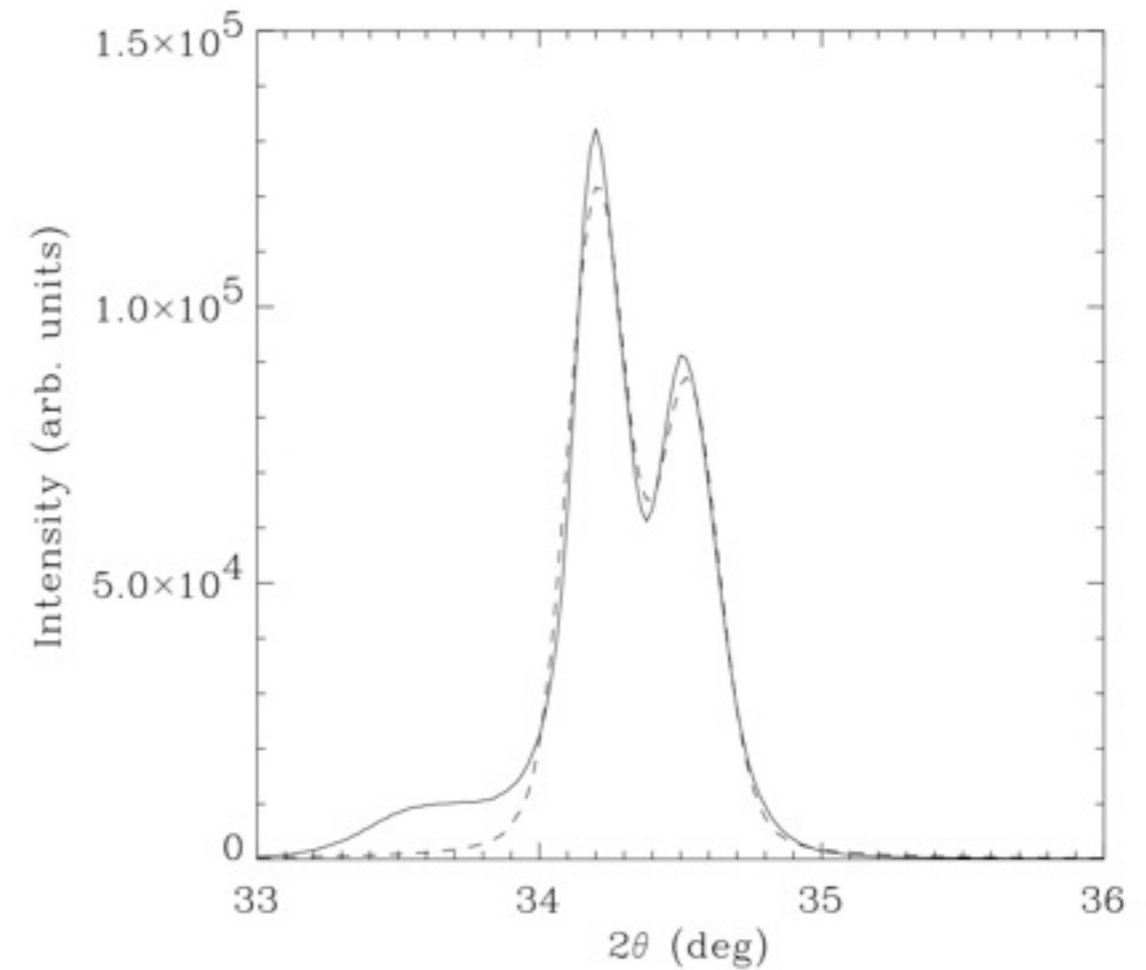
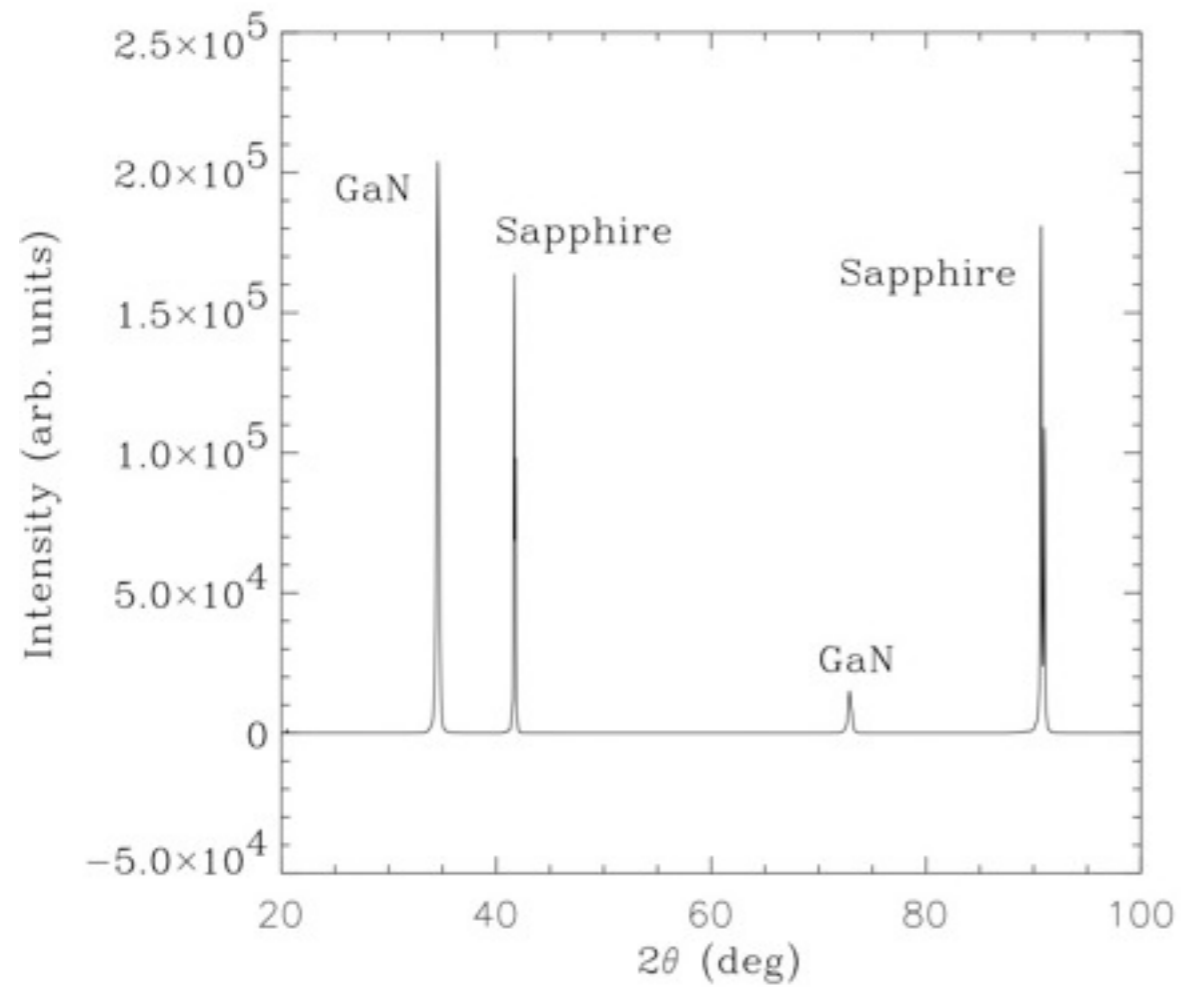
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Electron Diffraction

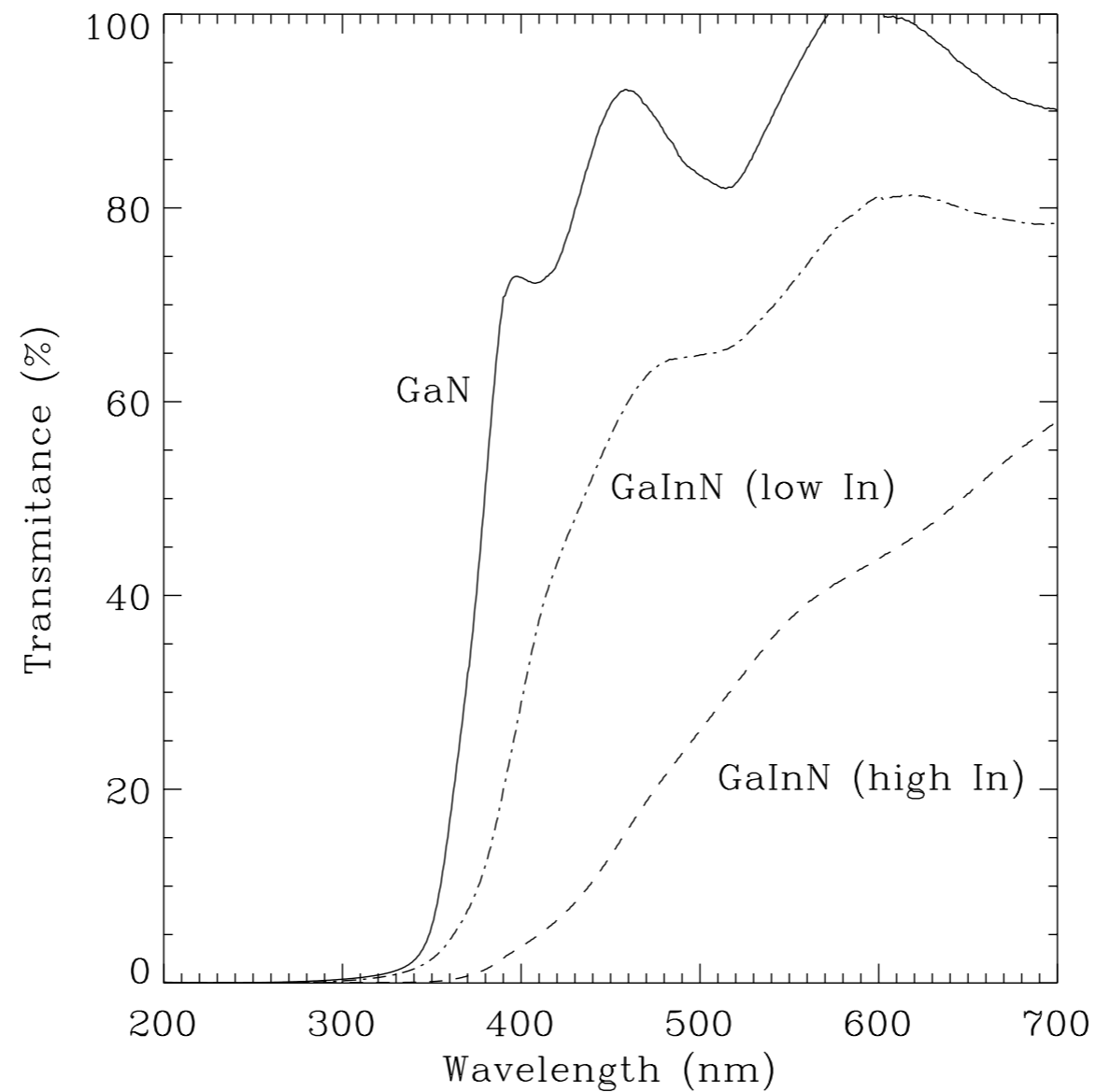


- During growth, Reflection High-Energy Electron Diffraction (RHEED) is used to monitor growth surfaces. At left a pattern showing good growth, but some atomic-scale irregularity over the 2" surface. At right, the pattern shows atomically smooth growth across the surface.
- We will use this as a tool to evaluate crystal growth as more Indium is incorporated. This year we plan to upgrade the camera/acquisition system and improve our quantitative analysis.

X-ray Diffraction

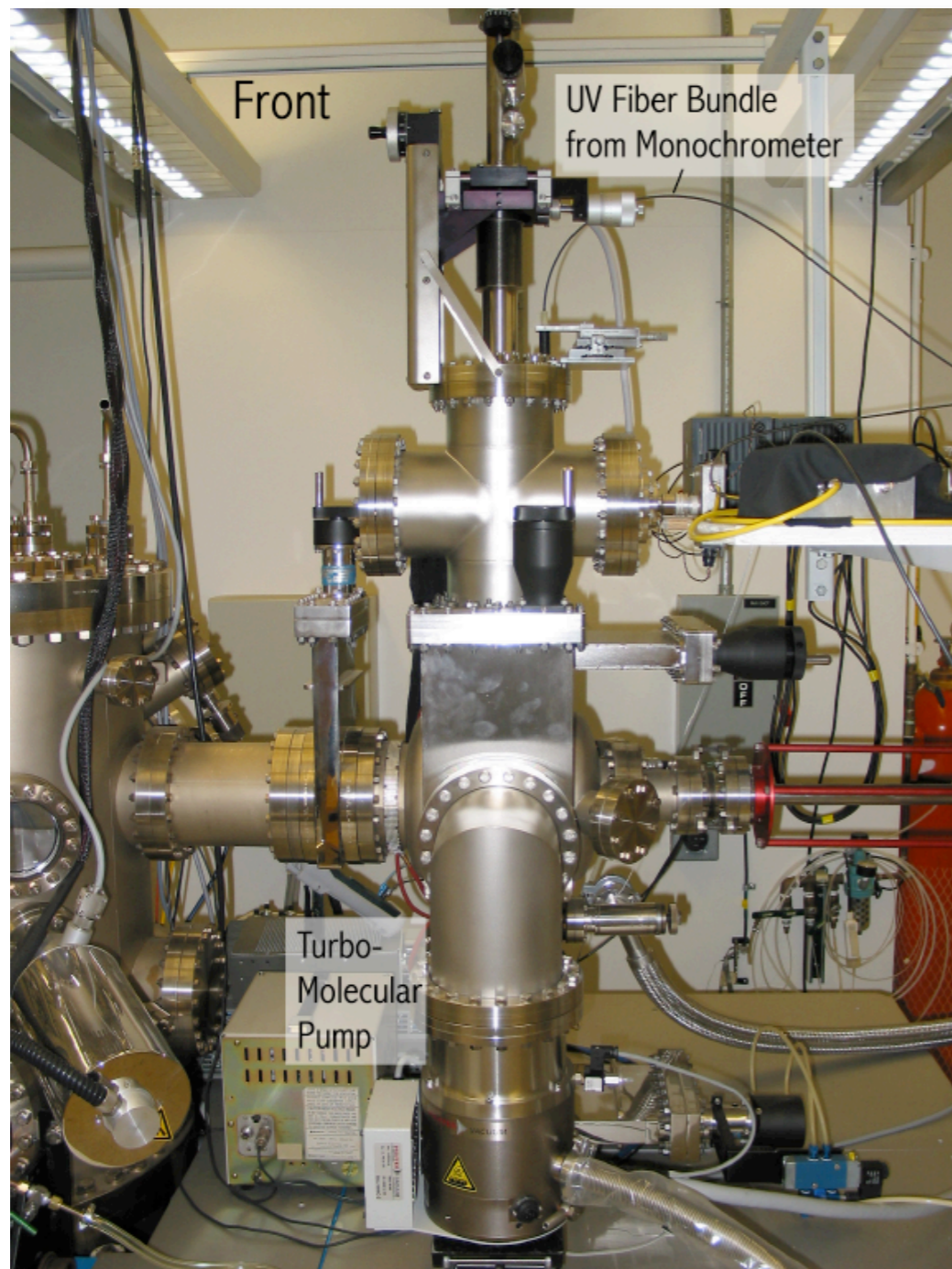


Optical Transmission

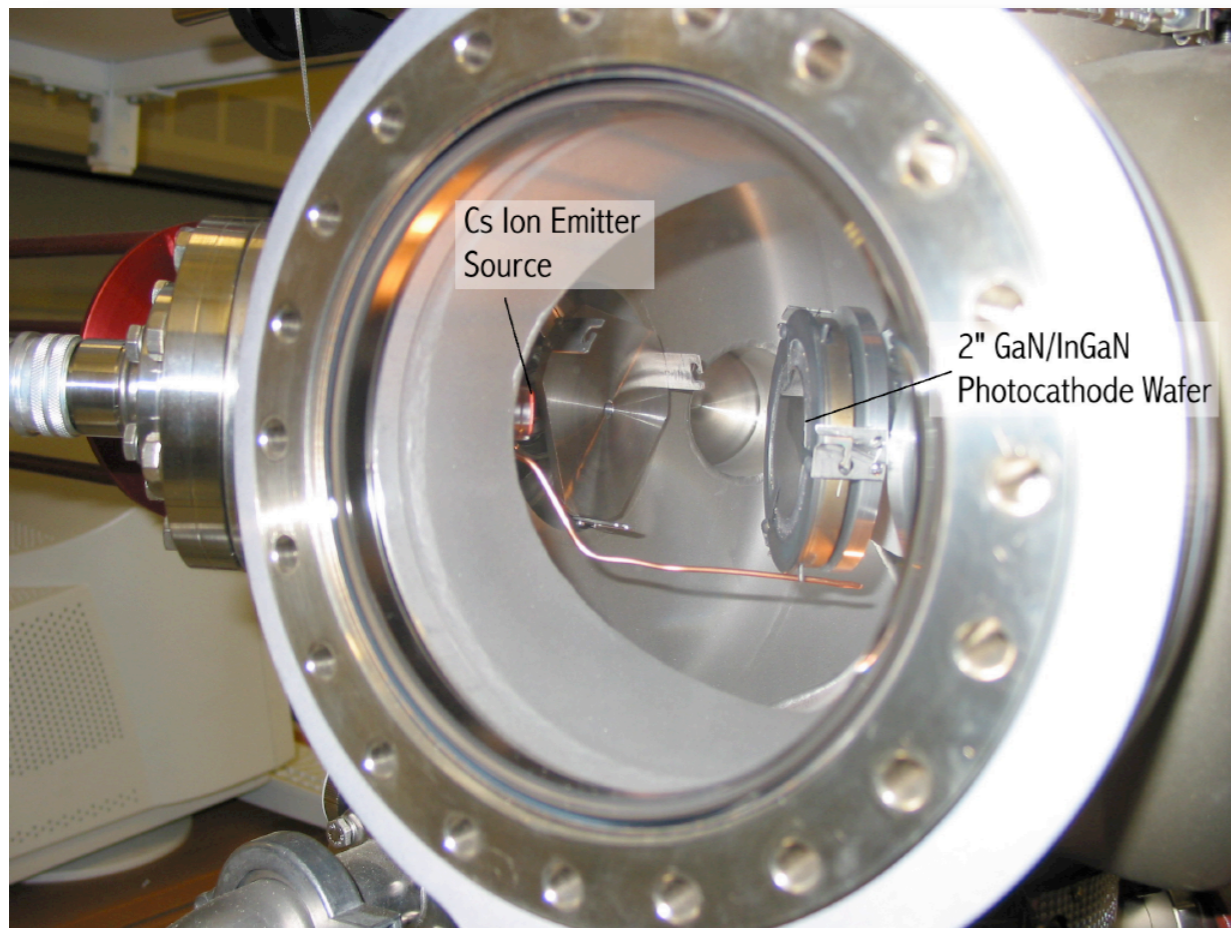


- Alloying with In shows a shift to larger wavelengths (smaller bandgap)

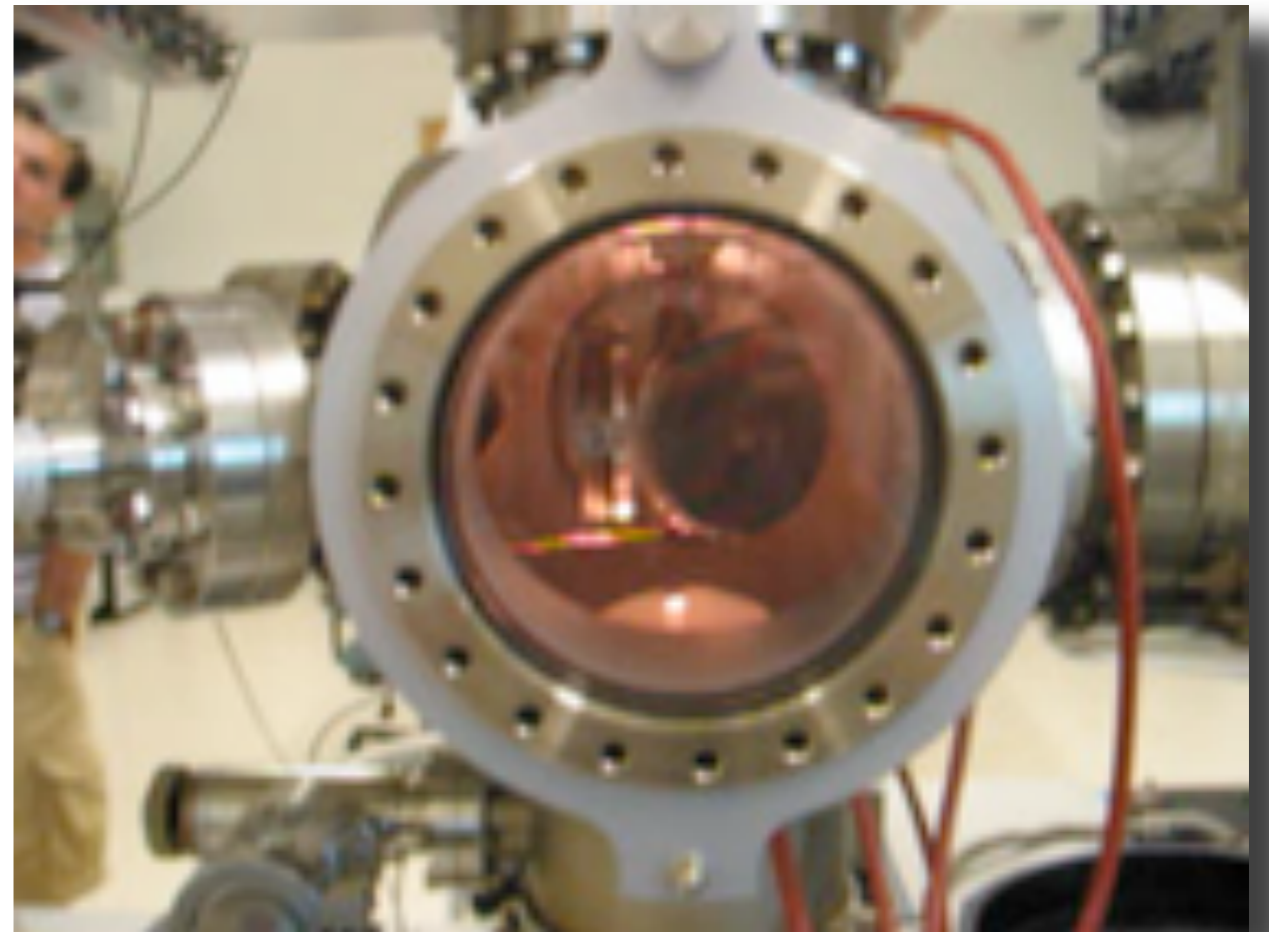
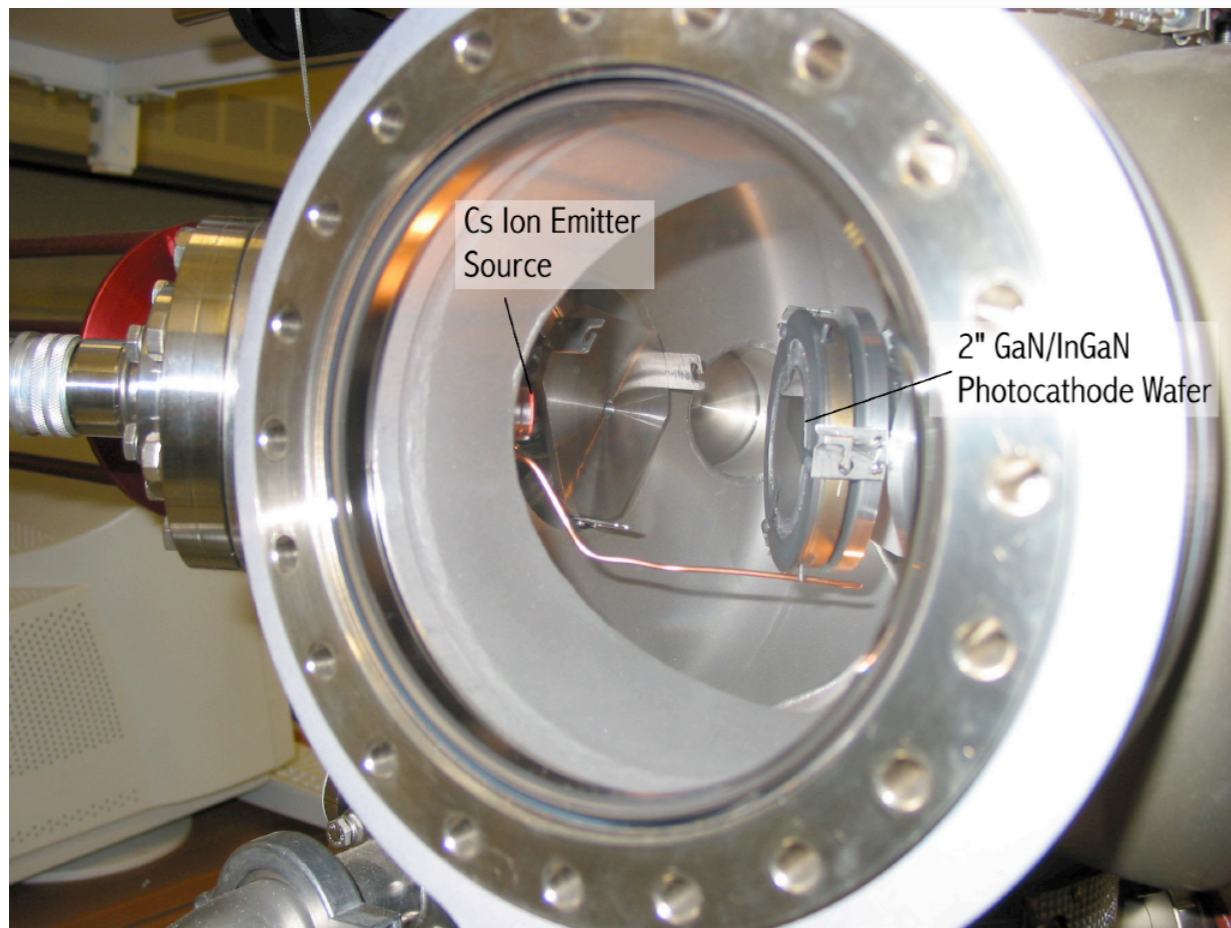
QE Measurement System



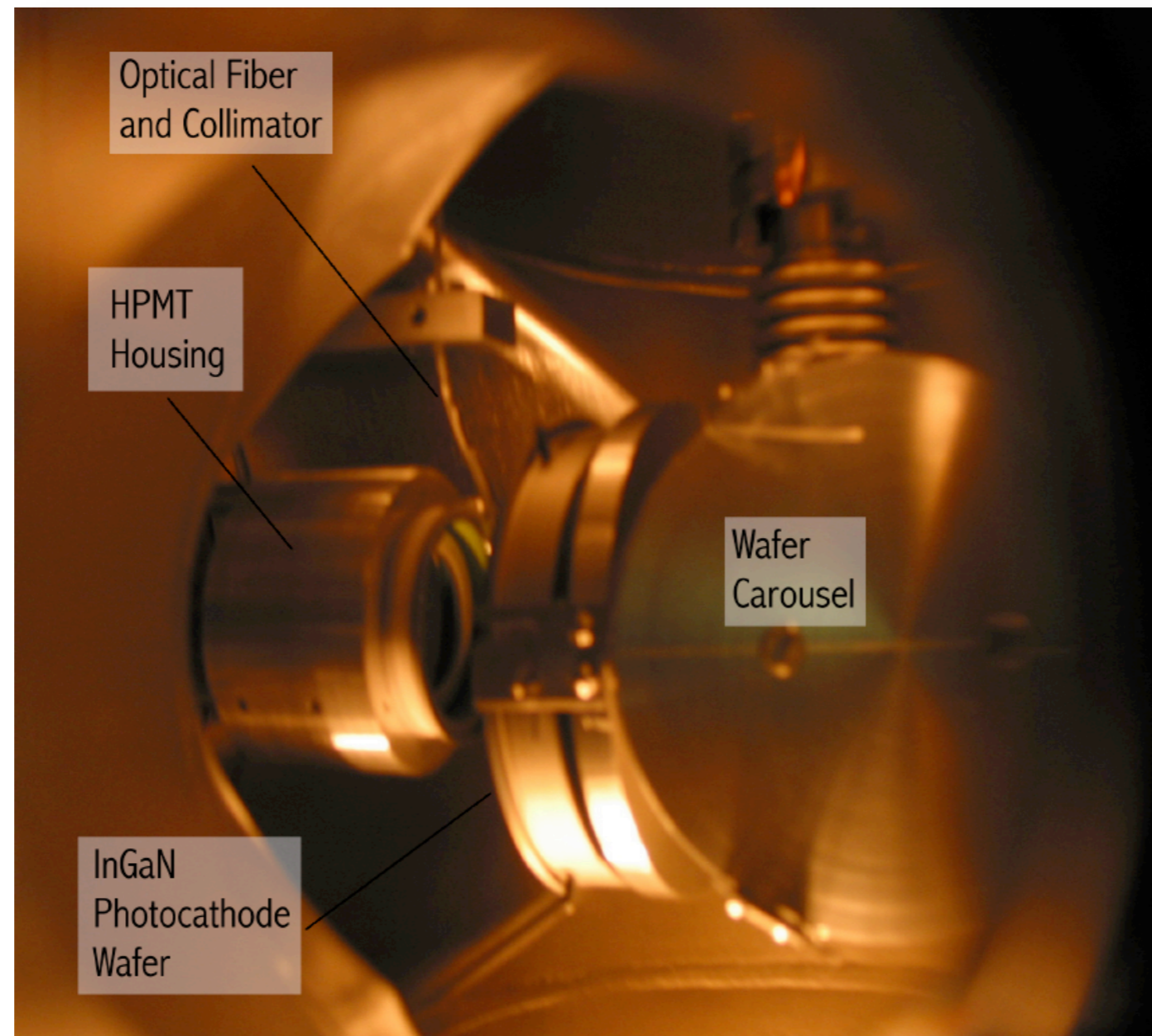
Cesium Activation



Cesium Activation

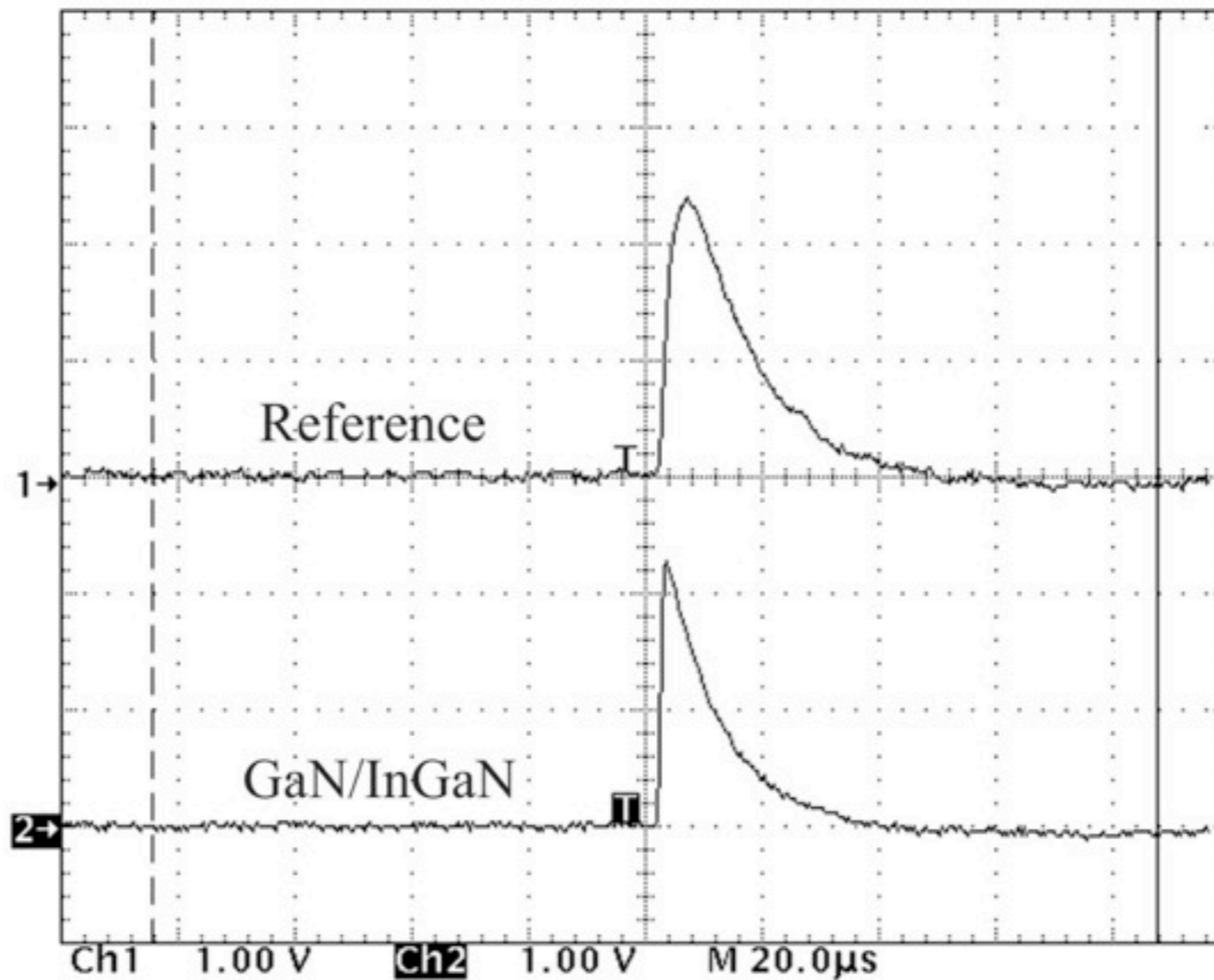


QE Measurement System



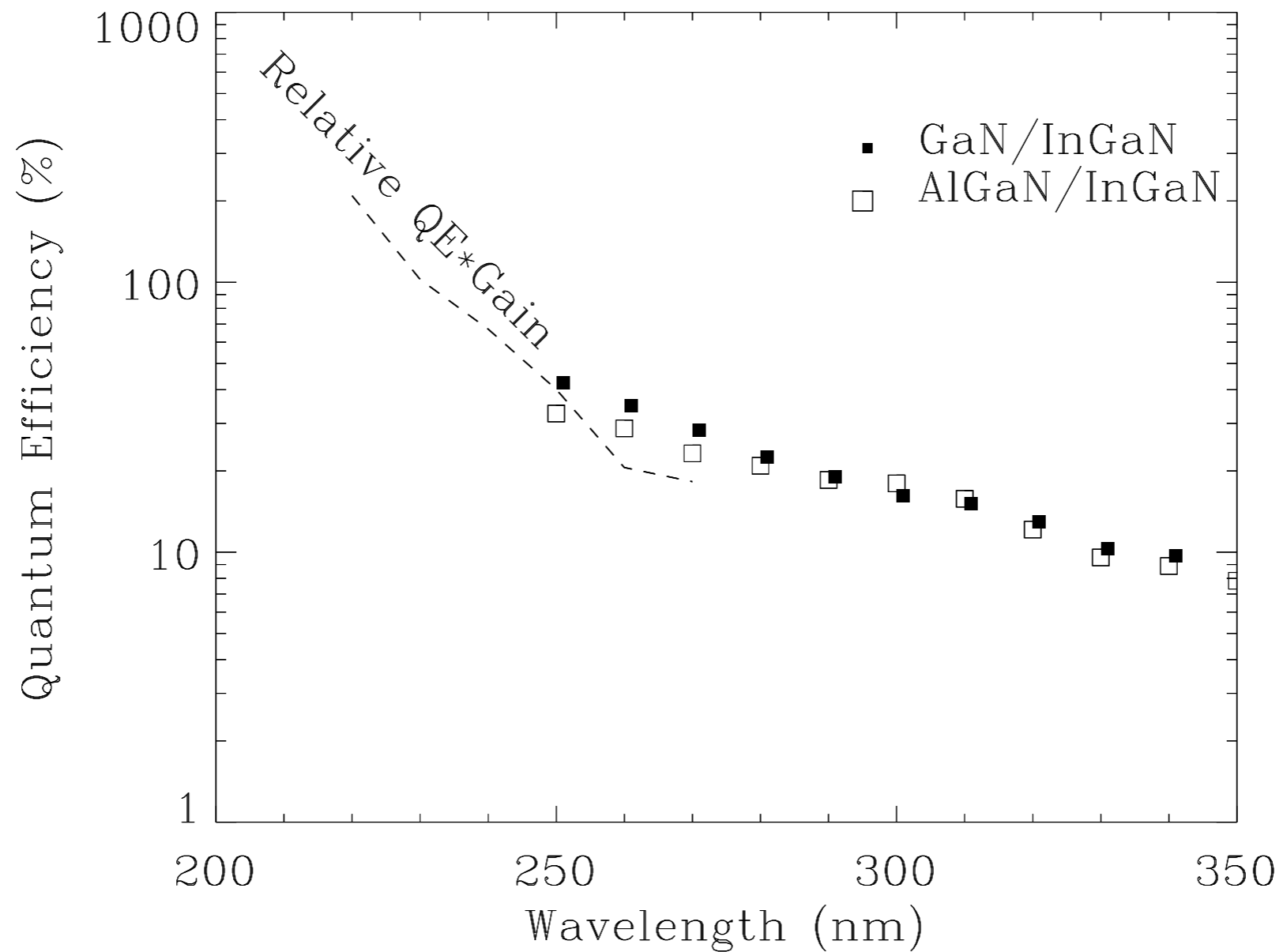
- Hybrid phototube with 7-pin photodiode array, and two independent HVs for gain and cathode bias
- UV-fiber coupled signal from monochromatic pulsed light source

Quantum Efficiency

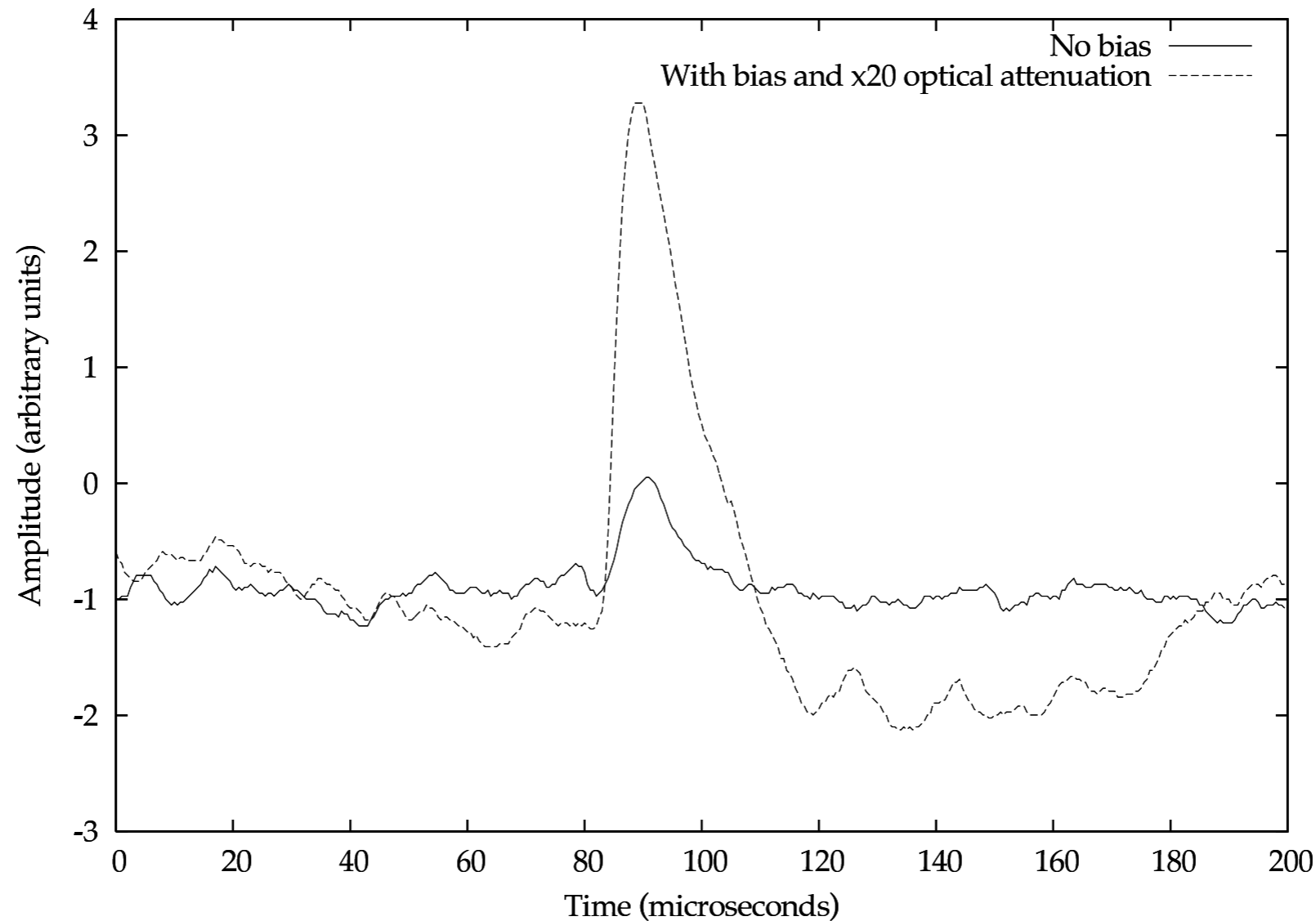


- Electronic pulses from HPMT pin diode and reference photodiode registered by low-noise-amplifier electronics.

QE Wavelength Dependence

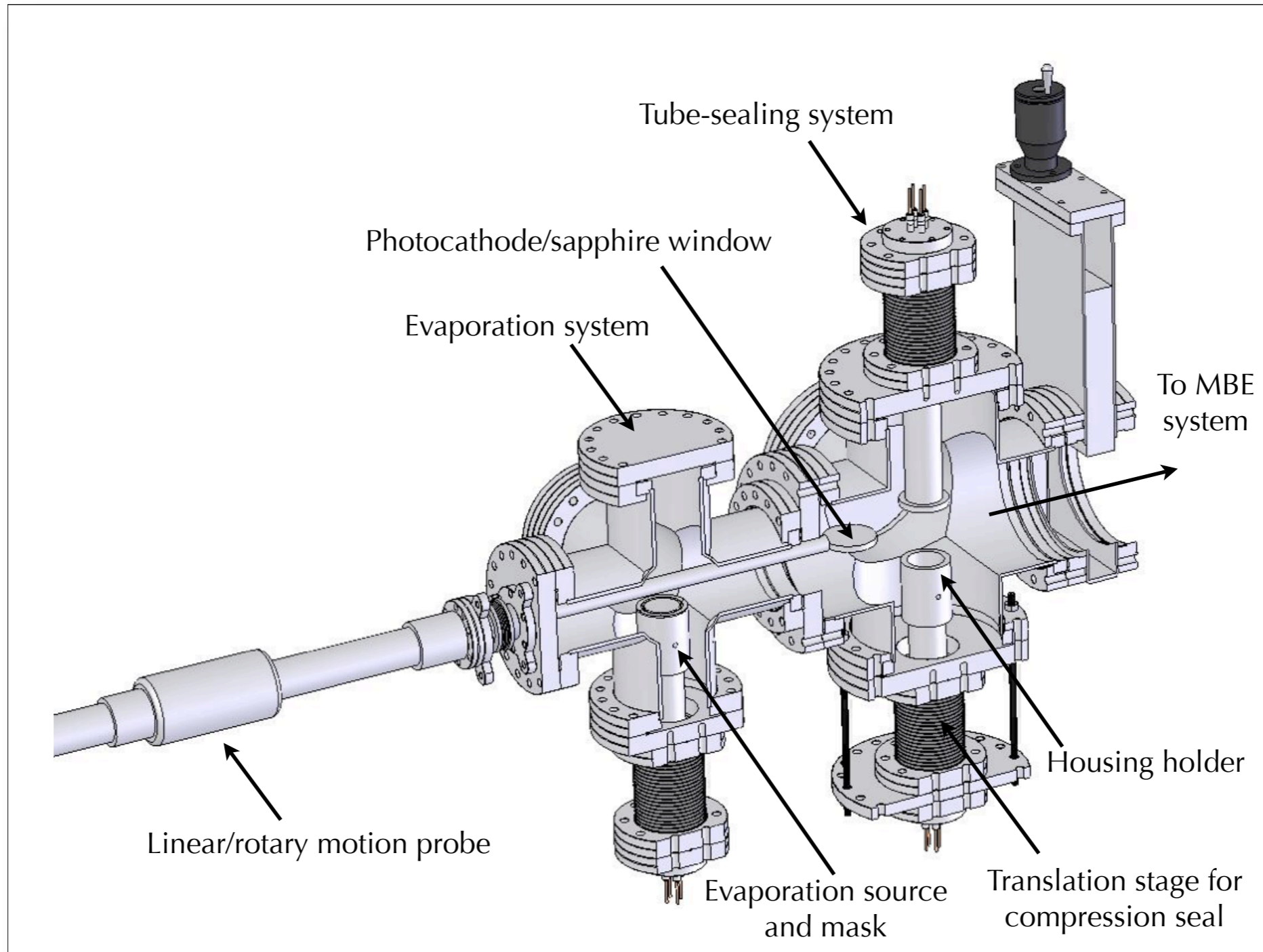


Voltage Bias

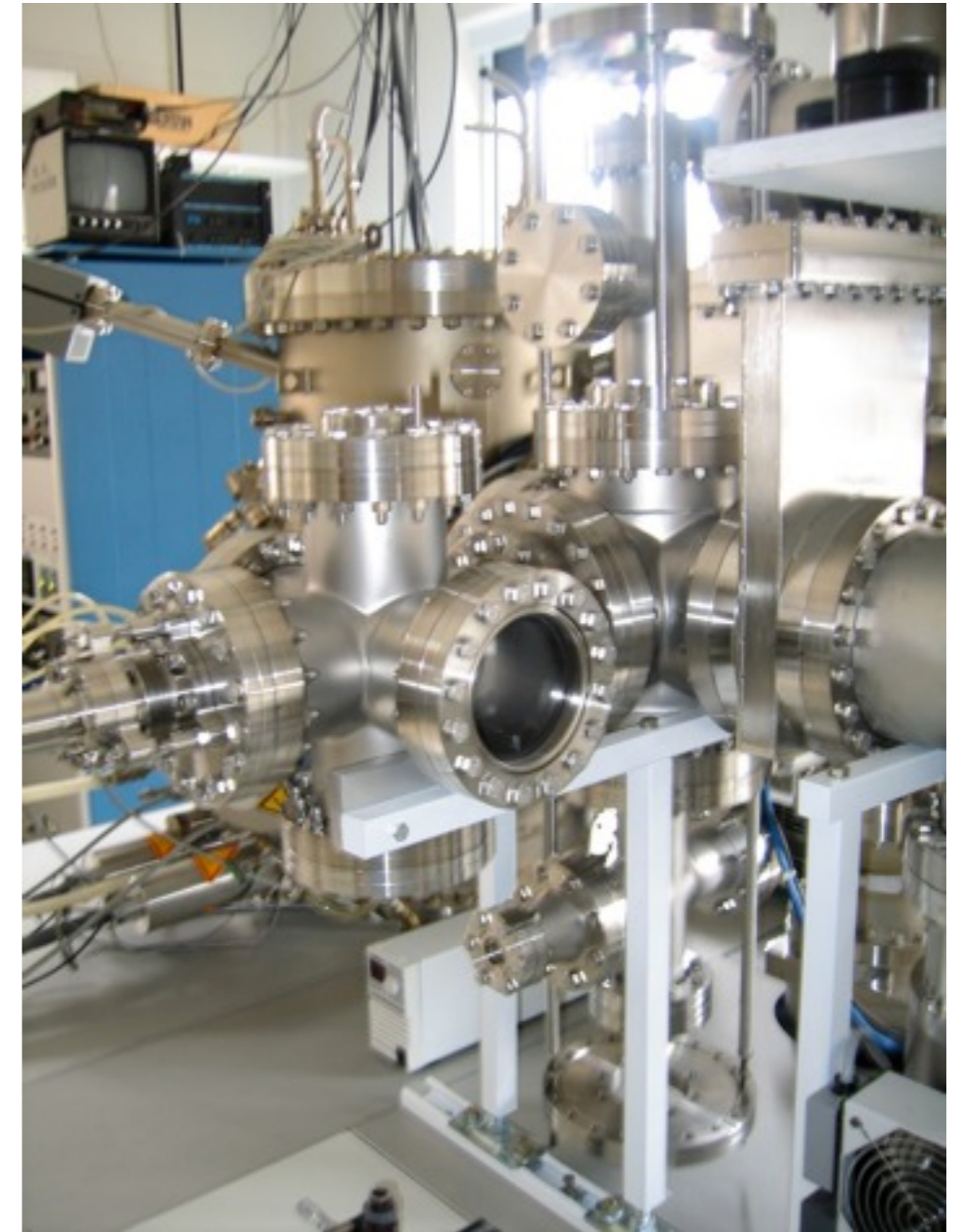


- Pulse signal with and without electrical bias applied across cathode surface.
- Applied voltage gain to aged surface results in a dramatic improvement in the gain-QE product.

Tube-Sealing System

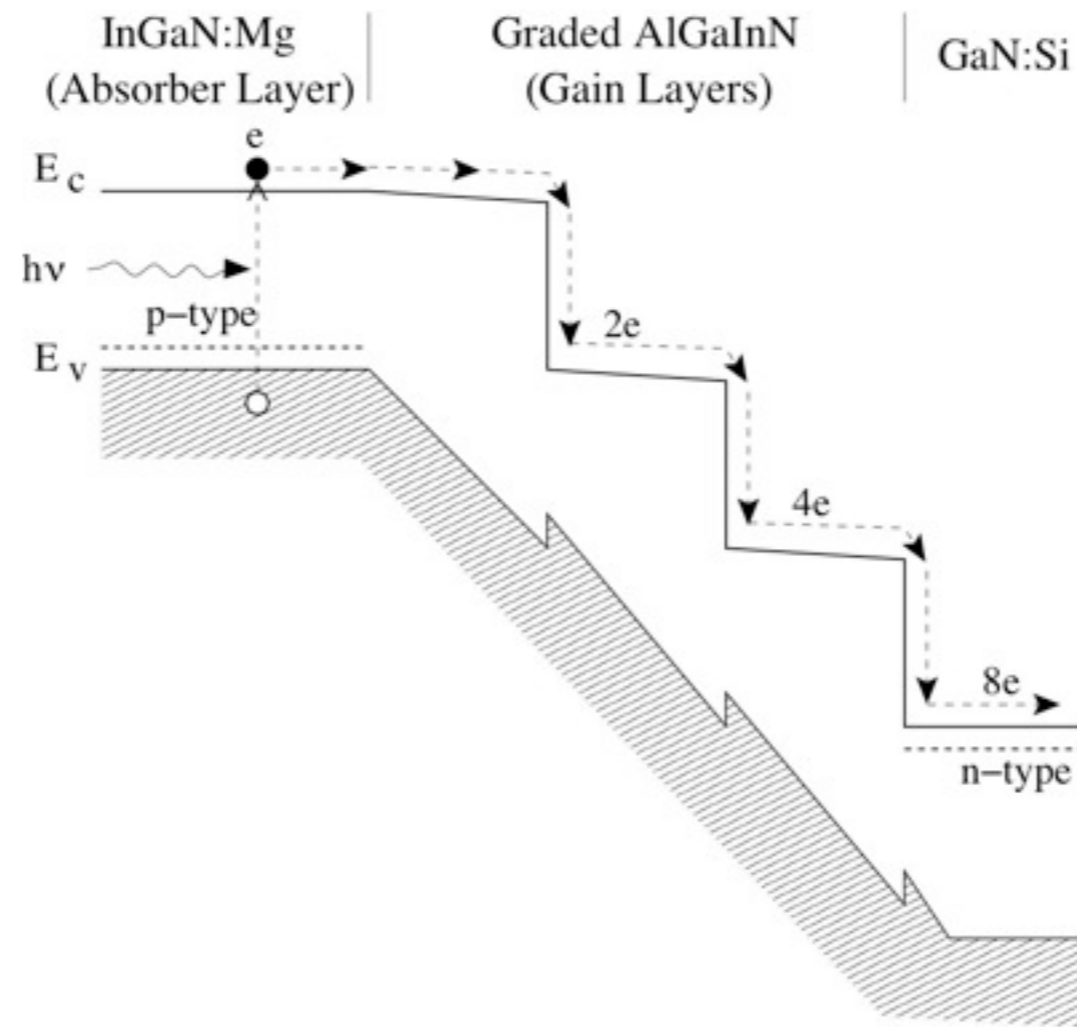


Status



- Construction of tube-sealing system
- Developing methods for in-situ calibration
- New methods for cathode transfer (restoring aged surfaces)

Internal-Gain Device Concept



- Energy band-edge profile of photocathode heterostructure with discrete gain stages. Initially we will explore hybrid devices including “cathodes with gain” for better detection efficiency.
- This fall, we added a gain layer (without grading dopant) to an old (cleaned) cathode. Obtained good crystal growth, and good QE but are still missing some elements for gain.

Summary

- Semiconductor nitride heterostructures look very promising as photocathodes specifically tailored in the UV/blue wavelength range.
- We have already demonstrated band shifting with Indium, should be possible to incorporate more Indium and extend sensitivity to 400 nm with different buffer layers and optimized growth parameters - studies are underway
- We have made progress in restoring surfaces with an atomic nitrogen beam, and with an applied bias voltage. These could aid in transfer of material from the growth system to complete devices.
- Our goals for the coming year are to optimize the long-wavelength response, experiment with growth on amorphous substrates and to develop an efficient mechanism to transfer material to other labs.

Acknowledgements:

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